(54) LINEARIZER
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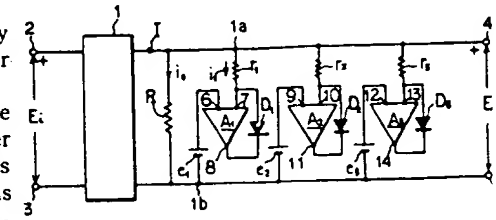
PURPOSE: To obtain a linearizer which is easy to be adjusted and is not drifted by temperature by combining multiple non-linear elements which form a non-linear function of an operational amplifier, diodes and a constant voltage power source.

CONSTITUTION: An input signal Ei is converted into current I. When the voltage drop I·R due to a resistance R is smaller than voltage of a constant voltage power sourse e_1, the outputs of operational amplifiers $A_1 \sim A_3$ take positives and diodes $D_1 \sim D_3$ become non-conductive. When the input voltage Ei increases and exceeds the voltages of the constant voltage source $e_1 \sim e_3$, the diodes $D_1 \sim D_3$ become conductive one after another and current flows through resistors $r_1 \sim r_3$ connected with reverse input terminals 7, 10, 13 of the arithmetic amplifiers $A_1 \sim A_3$ and output voltage E_0 is decreased.



1: voltage/current converter

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Inventor: Takashi Yoshioka
Applicant: Shimadzu Corp.
Title of the Invention:

LINEARIZER

Claims:

1. A signal converter for linearizing output signals by disposing nonlinear elements having a function approximate to a nonlinear function of input signals in a feedback circuit, a linearizer comprising:

constant voltage power supplies having individual threshold voltages and connected in common at their negative output terminals;

differential operational amplifiers connected at its noninverting input to the positive output of said constant voltage power supply; and

a plurality of nonlinear elements juxtaposed with one another, each of said nonlinear elements having a diode connected between the inverting input terminal and an output terminal of said differential operational amplifier so as to absorb a conduction current of said diode, said inverting input terminal being inserted to the positive output of the convertor through a resistor.

2. A signal convertor for linearing output signals by disposing nonlinear elements having a function approximate to a nonlinear function of input signals in a feedback circuit, a linearizer comprising:

a constant voltage power supplies having

individual threshold voltages and connected in common at their negative output terminals;

differential operational amplifiers connected at its noninverting input to the positive output of said constant voltage power supply; and

a plurality of nonlinear elements disposed in parallel at inverting and noninverting input terminals of one operational amplifier, respectively, each of said nonlinear elements having a diode connected between the inverting input terminal and an output terminal of said differential operational amplifier so as to absorb a conduction current of said diode; wherein:

a divided input voltage obtained by dividing the input voltage of said convertor by a resistor is applied to said noninverting input terminal and a divided output voltage obtained by dividing the output voltage of said convertor by a resistor is applied to said inverting input terminal so as to always establish an equilibrium between them.

3. A linearizer according to claim 2, which further includes switching means for selectively connecting a plurality of said nonlinear elements, which are to be connected in parallel with said inverting input and noninverting input terminals of said operational amplifier for establishing the equilibrium between the input divided voltage and the divided output voltage, to said inverting and noninverting input terminals.

3. Detailed Description of the Invention:

This invention mainly relates to a linearizer used for detection signal conversion in process measurement control. In process control of a centralized management system, all the process variables are once converted to a standard signal.

Among signal convertors, linearizers which linearize a nonlinear electrical output of a detection element and input it to a detector have been used in many cases, and their performance plays a vital role in process controllability. If the detection element described above is a thermocouple, for example, a temperature-electromotive force curve exhibit a maximum of about 10% nonlinearity in the case of platinum-platinum rhodium for a high temperature use, and chromel-alumel which has been used most widely in process has an S-shaped characteristic of about ±1% nonlinearity. To linearize them, nonlinear elements having the same nonlinear function as that of the input (temperature-electromotive force in this case) are interposed in a feedback circuit of an amplifier to obtain output proportional to the temperature. A typical linearizer according to the prior art connects, in parallel, series circuits comprising a diode, a resistor and a constant voltage source in the same number as the number of line segments in the feedback circuit of the amplifier. Because the feedback resistance sequentially decreases with the increase in the input, the gain of the amplifier drops and a nonlinear function approximate to an arbitrary broken line can be obtained. In this system, the diodes are turned ON at the respective predetermined voltages and currents flow through their circuits to provide broken-line characteristics. Therefore, this system is not free from the drawbacks that the adjustment of the currents flowing through the diodes and the constant voltage sources is difficult, and the very small change of the currents resulting from the influences of the ambient temperature, for example, results in the drift of the brake point of the broken-line characteristics. A linearizer which eliminates

the problem that the current directly flows through the diode and the power supply utilizes transistor as shown in Fig. 1 which represents its principle. In the drawing, reference numeral (1) denotes a converter for converting an input voltage (Ei) to a current (I), symbols (Tr1 to Tr3) denote transistors, (e1 to e3) denote constant voltage sources, and (r1 to r3) denote resistors. When the voltage drop (IR) across the resistor (R) becomes greater than the sum of the emitter-base voltage (V_{EB1}) of the transistor (Tr1) and (e1), the transistor (Tr1) is turned ON. (When IR further increases, the transistors Tr2, Tr3 are sequentially turned ON and the output voltage (E_0) is approximated to a broken line.) In this case, the major proportion of the current (i1) flowing through the resistor (r1) flow through the emitter-collector of the transistor (Tr1), and only a current equivalent to the reciprocal ($1/\beta$) of a current amplification (β) of the transistor (e1) flows through this transistor (e1) (generally, below 1/100). Therefore, the state is relatively stable. However, the transistor is sensitive to the change of the ambient temperature as the characteristics of semiconductors, so that (V_{EB1}) is likely to fluctuate and the drift of the break point described above is unavoidable.

In view of the background described above, the present invention aims at providing a linearizer which can easily adjust currents flowing through individual nonlinear elements, can obtain highly accurately arbitrary characteristics, can prevent the drift of the break point against disturbance such as the ambient temperature, and has high stability, by combining a plurality of nonlinear elements for generating a nonlinear function with operational amplifiers, diodes and constant voltage sources. In

other words, in a signal converter for linearizing output signals by disposing nonlinear elements having a function approximate to a nonlinear function of input signals in a feedback circuit, the present invention provides a linearizer which comprises a constant voltage power supply for holding an intrinsic conduction start voltage value by using in common a negative plate side of output terminals; differential operational amplifiers using a positive plate of the constant voltage power supply as a noninverting input; and a plurality of nonlinear elements juxtaposed with one another, each of the nonlinear elements having a diode connected between an inverting input terminal and an output terminal of the differential amplifier so as to absorb a conduction current of the diode, the inverting input terminal being inserted to the positive plate side of the converter output terminal through a resistor.

Hereinafter, an embodiment of the present invention will be explained in detail with reference to the accompanying drawings.

Fig. 2 is a structural view of a linearizer which reduces an output voltage (E_0) with the increase in an input voltage (Ei) by using a voltage/current converter (1). Reference numerals (2) and (3) denote input terminals, and (2) is a positive terminal and (3) is a negative terminal. Reference numerals (4) and (5) denote output terminals, and (4) is a positive terminal and (5) is a negative terminal. Symbols A1 to A3 denote differential input type operational amplifiers, symbols D1 to D3 denote diodes, and the rest are the same as those in Fig. 1. Reference numerals (6), (9) and (12) denote noninverting terminals of the operational amplifiers A1 to A3 and reference numerals (7), (10) and (13) denote their

inverting terminals. Reference numerals (8), (11) and (14) denote the output terminals of the operational amplifiers. In the case of the voltage drop ($i_0R < e1$) across the resistor (R), (8) of A1 is at a positive potential and the diode (D1) is non-conductive. When (Ei) increases and ($i_0R > e1$), (8) of A1 becomes negative, the diode (D1) becomes conductive and the voltage (E7) of the inverting input terminal (7) of A1 becomes equal to the voltage (e1) of the noninverting terminal (6). In this case, the major proportion of the current (i1) flowing through (r1) pass through the diode (D1), are absorbed by the power supply inside the amplifier (A1) and do not flow through (e1). This is one of the requirements of the present invention.

The offset voltage/current between the input terminals (6), (7) of the amplifier (A1) is ordinarily about 0.1% of (Ei) and this value can be practically neglected. However, a linearizer capable of completely regulating this offset to zero may be used, too. The portion between (1a) and (1b) of the nonlinear element under this equilibrium condition of ($E\eta$ = e1) becomes equivalent to a series circuit of (r1) and (e1). This will be explained with reference to Fig. 3 wherein the output current (I) of the block (1) is plotted on the abscissa and the voltage (E_0) of the output terminals (4), (5) is plotted on the ordinate. When the output current (I) exists between 0 and I', e1 > IR, and the portion between (1a) and (1b) is non-conductive. When E_0 = IR, the characteristics are represented by a solid line (C1). When (I) increases from (I'), (D1) becomes conductive and a current $i_1 = \frac{E_0 - e_1}{r_1}$ flows through (r1) but does not flow through (e1) as described above. Accordingly, increase in E_0 is expressed by:

$$E_0 = \frac{R}{1+R/r_1} \cdot 1 + \frac{R/r_1}{1+R/r_1} \cdot e_1 \qquad \ldots (1)$$

as expressed by the equation (1), the characteristic increase with the increase in the current (I) at a gradient (C2) at a proportional constant determined by (e1), (E1), (r1), and characteristics having a gradient (E_0") are obtained at (I_F). Though Fig. 3 shows the characteristics of one line graph for simplification, the break point increases by two when (e2) and (e3) shown in Fig. 2 are arbitrarily set to e1 < e2 < e3, and the characteristic of this linearizer becomes approximate to a protruding broken line. The above explains the construction and operation of the linearizer having the characteristic approximate to the broken line by a plurality of nonlinear elements as one of the essential conditions of the present invention.

Next, an embodiment of a linearizer capable of arbitrarily obtaining S-shaped (inverted S-shaped) characteristic and having a broad range of application as the second essential condition of the present invention will be explained with reference to Fig. 4. Explanation of the circuit elements having the same reference numerals as in Fig. 2 will be omitted. The feature of this circuit construction resides in that nonlinear elements (A1, D1, e1), (A2, D2, e2) are connected to a foward circuit (circuit of the noninverting input terminal (15)) of the operational amplifier (A_0) having a high gain, and nonlinear elements (A4, D4, e4) (A5, D5, e5) are similarly connected to the feedback circuit (circuit of the inverting input terminal (16)). The operation of this circuit will be explained. If four sets of nonlinear elements do not exist, that is, if the circuit comprises only (A_0) and four equivalent resistors (R1

to R4), the potential at (15) of (A_0) is ($E15 = Ei/2$) and the potential at (16) is ($E16 = E_0/2$). Therefore,

$$E_0 = Ei \qquad \ldots \quad (2)$$

Next, when the four nonlinear elements are added as shown in Fig. 4 and under the condition of ($e1 = 0$) and ($e1 < e2$ and $e4$ and $e5$), the portion between (1a) and (1b) becomes the equivalent circuit of only (r1). Therefore, (Ei) in this case is given by:

$$E_0 = \frac{1}{1+R/2r_1} \cdot Ei \qquad \ldots \quad (3)$$

Accordingly, the characteristics become the characteristic approximate to the protruding broken line as explained with reference to Figs. 2 and 3, and the gradient (C3) shown in Fig. 5 can be obtained. As (Ei) further increases, the potential of (15) of (A_0) rises and then ($E15 > e2$). At this time, the diode (D2) becomes conductive, and the potential at its inverting terminal (10) becomes ($E10 = e2$). As described already, the equivalent circuit of (2a) and (2b) becomes a series circuit of (r2) and (e2), and the current $(E15 - e2)/r2$ flows through (r2). (In this case, too, the current does not flow through (e2) in the same way as described above.) Moreover, due to the equilibrium condition of ($E15 = \frac{E_0}{2}$), (E_0) at this time is given by:

$$E_0 = \frac{Ei + \frac{R}{r_2} \cdot e2}{1 + \frac{R}{2}(1/r_1 + 1/r_2)} \qquad \ldots \quad (4)$$

The gradient characteristic of (C4) in Fig. 5 can be thus obtained. As (Ei) further increases, the potential of the terminal (16) of (A_0) rises and the relation ($E16 > e4$) is reached, the diode (D4) is turned ON. Therefore, E_0 becomes as follows:

$$E_0 = \frac{1+R/2r_4}{1+\frac{R}{2}(1/r_1+1/r_2)}(Ei+\frac{R}{r_2}\cdot e_2)\frac{R}{r_4}\cdot e_4 \quad \ldots (5)$$

The characteristic becomes a curve approximate to a protruding broken line such as (C5) in Fig. 5. As (Ei) further increases and the relation (E16 > e5) is reached,

$$E_0 = \frac{1+\frac{R}{2}(1/r_4+1/r_5)}{1+\frac{R}{2}(1/r_1+1/r_2)}(Ei+\frac{R}{r_2}\cdot e_2)-(\frac{R}{r_4}\cdot e_4+\frac{R}{r_5}\cdot e_5) \quad \ldots (6)$$

and the gradient shown in (C6) of Fig. 5 can be obtained. Because the gradient can be thus raised or lowered as described above, characteristic approximate to an arbitrary line graph can be obtained. When the intrinsic value of each component is determined for the four nonlinear elements in accordance with the relational formulas (2) to (6), the inverted S-shaped characteristic shown in Fig. 5 can be obtained. The above explains the construction and the operation of the linearizer according to the second essential requirement of the present invention.

The number of the nonlinear elements shown in Fig. 4 can be increased to any number in such a manner as to correspond to the nonlinear function of the input. In other words, a required number of nonlinear elements may be added to the terminal (15) of (A_0) so as to lower the gradient and may be added to the terminal (16) so as to raise the gradient. However, when it is desired to obtain an arbitrary gradient by using four approximate lines as shown in Fig. 5, four nonlinear elements for each input terminal (15), (16), or eight in total, are necessary. In this case, an arbitrary gradient can be obtained by extending four junctions (a to d), (a' to d') from the input terminals (15), (16), respectively, as shown in Fig. 6, and switching four nonlinear elements (La to Ld) by

switches (Sa to Sd). In this way, an arbitrary gradient selection type linearizer can be constituted. A nonlinear relational input having various gradients can be linearized by minimum nonlinear elements by changing arbitrarily the junctions by short jumpers in place of the switches. Further, if (r1 to r4) in Fig. 4 are variable resistors, the selection range of the gradient becomes further broader. The initial proportional coefficient can be changed by setting four resistors (R1 to R4) to different values.

Having the construction described above, the present invention can eliminate the drawbacks with the conventional linearizers using the diodes or the transistors, can set with high accuracy the break point by determining the intrinsic value of each electronic component in accordance with the formulas (1) to (6), and can be converted arbitrarily to a variable type. Furthermore, the linearizer according to the present invention has high stability without being affected by disturbance such as a temperature, and can simplify its construction and can reduce the size because the constant voltage source uses in common the power supply for the input/output and operational amplifiers. In short, the present invention can provide a linearizer which will be effective for process equipment having higher quality.

4. Brief Description of the Drawings:

Fig. 1 is a structural view of a linearizer utilizing transistors according to the prior art;

Fig. 2 is a structural view of a linearizer having a characteristic approximate to a protruding broken line;

Fig. 3 is an explanatory view of the operation of the linearizer shown in Fig. 2 (example of one line);

Fig. 4 is a structural view of a general-purpose

linearizer according to the present invention;

Fig. 5 is a diagram showing the characteristic of the linearizer shown in Fig. 4; and

Fig. 6 is a structural view of a linearizer of the type which can select an arbitrary gradient by using the minimum necessary number of nonlinear elements.

Ei ... input voltage (electrical output of detection device)

E_0 ... linearizer output voltage

e ... constant voltage source

Tr ... transistor

A ... differential input operational amplifier

D ... diode

B1 ... brake point

La to Ld ... nonlinear element comprising r, A, D and e

Sa to Sd ... change-over switch